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QUALITY ASSESMENT OF CASTING FILLING METHOD

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Abstract

The reliability of cast components is dependent on the quality of the casting process. This can be characterised by the robustness (repeatability) and specific fluid flow characteristics within the running system. During this transient filling phase the prevention of free surface turbulence and thus oxide entrainment is critical to the mechanical integrity of the component [1,2,3]. Past research has highlighted that return waves are major causes of free surface entrainment [4]. To reduce the entrainment occurring during the transitional filling of the runner a steady quiescent flow must be developed.

Using ***FLOW-3D***[1], the Froude number was extracted to allow the quantitative assessment of air entrainment for four different designs of sump at the end of the runner. The results show that, for the designs used, the addition of a correctly designed sump can be advantageous. However, an incorrect design may reduce the Froude number but can greatly increase the persistence of the return wave and entrainment and is therefore extremely detrimental to the cast component. Additionally, the in-gate design is of utmost importance in controlling the back pressure and thus the persistence of the back wave between the in-gate and the downsprue exit. This has a direct effect of the level of oxide entrainment.

Introduction

The return wave [1] is known to be a highly entraining flow regime common in many casting systems during the period of transient filling. The use of low profile runners, i.e. a height of less than the sessile drop height of the fluid has been advocated to stop this regime occurring [5,6]. However this is not always possible due to; manufacturing constraints, lack of flow control for multiple gated systems etc.

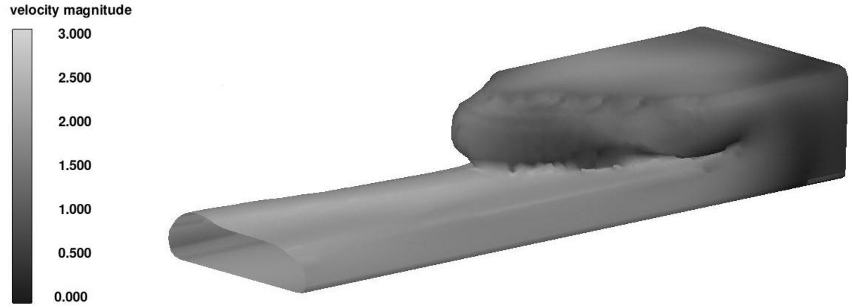


Figure 1. Highly entraining return wave

[1]***FLOW-3D*** is a CFD software developed by Flow Science Inc; 683 Harkle Rd. Ste A, Santa Fe, NM 87505

The availability of quantitative data will allow the casting engineer to optimise the running system design to improve casting integrity. The Froude number has been used in casting applications previously for uphill teeming of steel ingots [7]. It has been proposed that it would be useful in the assessment of the tendency towards the development of waves in the running system [8]. Planned future work will correlate this criterion with experimental data.

Assessment Criterion

The Froude number (*Fr*) is defined as the ratio of initial and gravitational forces and can be represented by Equation 1 & 2:

$$Fr^2 = \frac{\rho l^2 v^2}{\rho l^3 g} = \frac{v^2}{gl} \tag{1}$$

$$Fr = \frac{v}{\sqrt{gl}} \tag{2}$$

Where; ρ is density (kgm^{-3}), l is characteristic length (m), v is characteristic velocity (ms^{-1}), and g is the gravitational acceleration (ms^{-2}).

The Froude number has commonly been used by civil engineers to assess air entrainment in hydraulic structures. Research has shown a Froude Number >1.7 entrains air [9] [Figure 2].

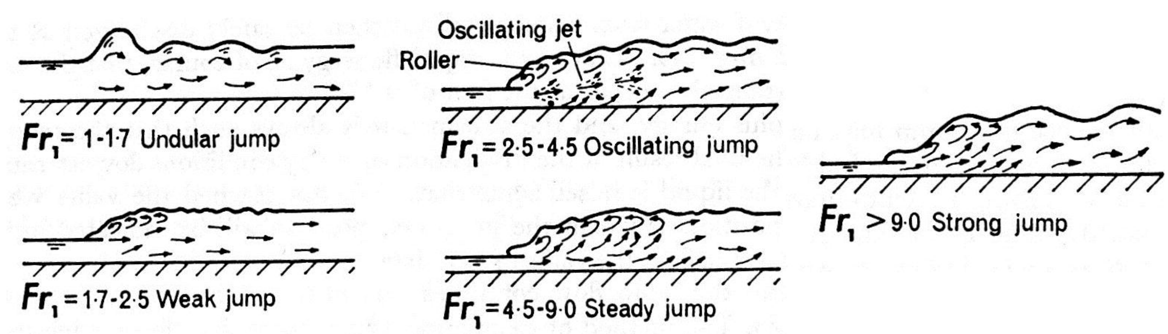


Figure 2. Entrainment magnitude schematic [9]

The Froude number has been modified to allow quantitative assessment of return waves as seen in Equation 3.

$$Fr = \frac{v_1 - v_2}{\sqrt{gl}} \tag{3}$$

Where v_1 is the average entry velocity and v_2 is the average return wave velocity as depicted in Figure 3. A sub-routine has been written for ***FLOW-3D*** to allow the extraction of this criterion at a predetermined time period.

To obtain the Fr number variables are defined for the subroutine in an input file. These are: cell plane and mesh block in which to undertake the calculation, cell values for both the top and bottom of the runner, height at which to scan to find the metal front, and the predetermined time step at which to undertake the operation.

The sub-routine takes the following steps to obtain the Fr number for each predetermined time step (Figure 3):

1. The cells along the predefined plane at the defined height are scanned until a cell with fluid is detected.

2. The cells in the vertical plane are then scanned to check they are full of fluid. If the cells in this column are not full of fluid the next column is assessed until the first column of full fluid cells is found.
3. From the predefined top cell the column is scanned searching for a change in flow direction. If more than one change of flow direction is found an output of -1 is given to indicate turbulent flow.
4. The distance from the cell where the flow direction changes to the predefined bottom cell in the runner is labelled l.
5. The average velocities v_1 and v_2 are calculated.
6. The Fr number is then calculated using the values of l, v_1 and v_2 obtained using Equation 3. This is then output to a text file.

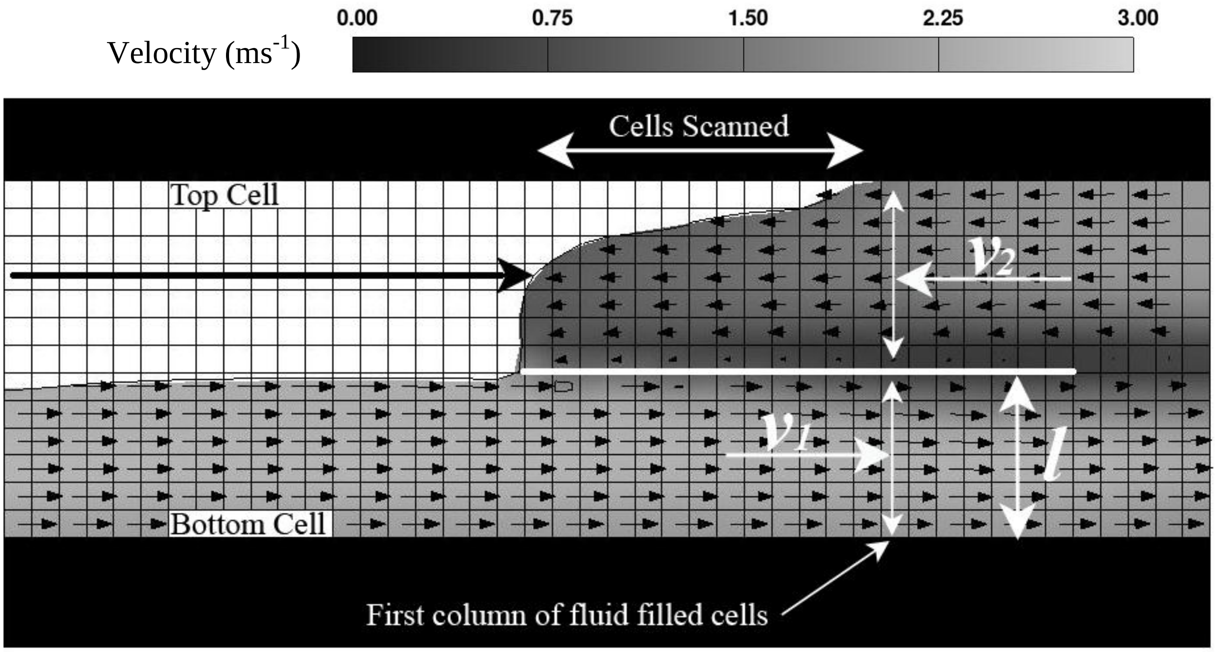


Figure 3. 2D Return wave showing Fr calculation method

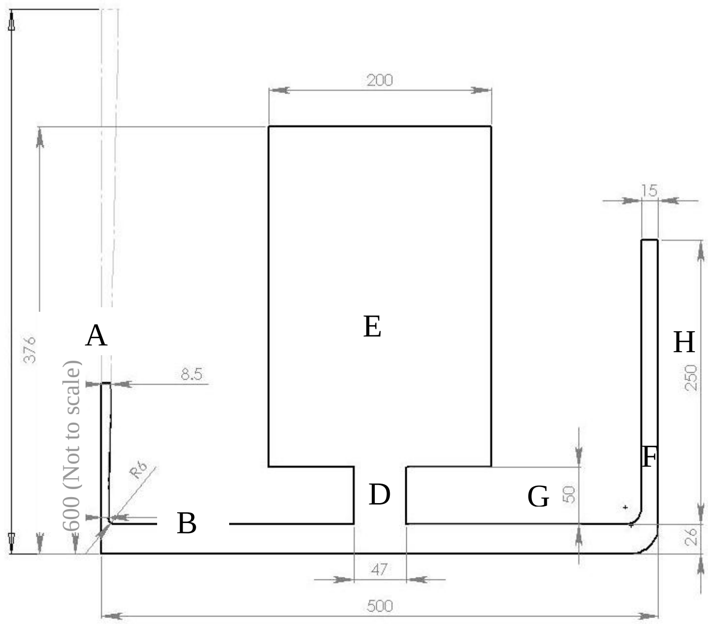
Sumps

The addition of a sump to a casting running system has historically had different levels of success. Two main reasons for addition have been identified. The first is to capture the initial fluid volume which is believed to contain the highest concentration of oxide films and other inclusions, thus stopping this fluid volume entering the casting [10]. For this reason the sump is often also known as a 'dross trap'. The second is to dissipate energy so as to reduce free surface turbulence during the transient filling of the running system [11].

Experimental Design

A simple running system was designed which conformed to known 'best practice principles' for a medium sized aluminium casting using a mass flow rate of 2.54 kgs^{-1} and a sprue exit velocity of 3.5 ms^{-1} [2] (Figure **4**). Three different in-gate heights and three different sump heights, in addition to a "no sump" case were chosen. A full experimental matrix was simulated and the Fr number data extracted (Table I).

As can be seen in Figure 4 not all of the down sprue was modelled. This was to save computation time. However enough downsprue was modelled to allow a parabolic fluid front to form before impacting with the runner bar, using a pressure equivalent to a total head height of 0.6 m. Therefore the results are in no way affected.



A	Downsprue (not to scale)
B	Modelled downsprue
C	Runner
D	In-gate
E	Casting volume
F	Sump
G	In-gate height
H	Sump Height

Figure 4. Running system designed to best practice principles. (Trial 5)

Results

The extracted Fr number results were integrated with respect to time to give a total damage value for each trial (Table I).

Table I: Trial Matrix and Results

Trial	Sump height (mm)	In-gate height (mm)	Total Fr	Running system Filling Time (s)
1	500	25	11646.13	1.93
2	500	50	11420.91	1.85
3	500	100	8170.50	1.48
4	250	25	9892.41	2.03
5	250	50	8520.82	1.73
6	250	100	6498.81	1.42
7	125	25	10230.44	2.00
8	125	50	8888.40	1.75
9	125	100	6058.59	1.27
10	0	25	10071.36	1.76
11	0	50	9368.87	1.65
12	0	100	7695.52	1.36

Discussion

These results show the best case to be Trial 9 (125 mm sump & 100 mm in-gate) and the worst Trial 1 (500 mm Sump & 25 mm In-Gate). The single highest Fr value of 11.96 was in Trial 13 and the single lowest an Fr of 2.57 in Trial 6, therefore all values exceed the 1.7 entrainment threshold.

The persistence of the wave has a large effect on the total damage. The 92% increase in the damage for Trial 1 when compared to Trail 9 was largely due to the increased persistence (Figure 6).

Statistical Analysis

An ANOVA (Analysis of Variance) was carried out which showed both variables to be significant to a 5% significance level; the in-gate was shown to be the most significant at 0.1% compared to the sump at 3.3% significance. Low level interactions were also identified.

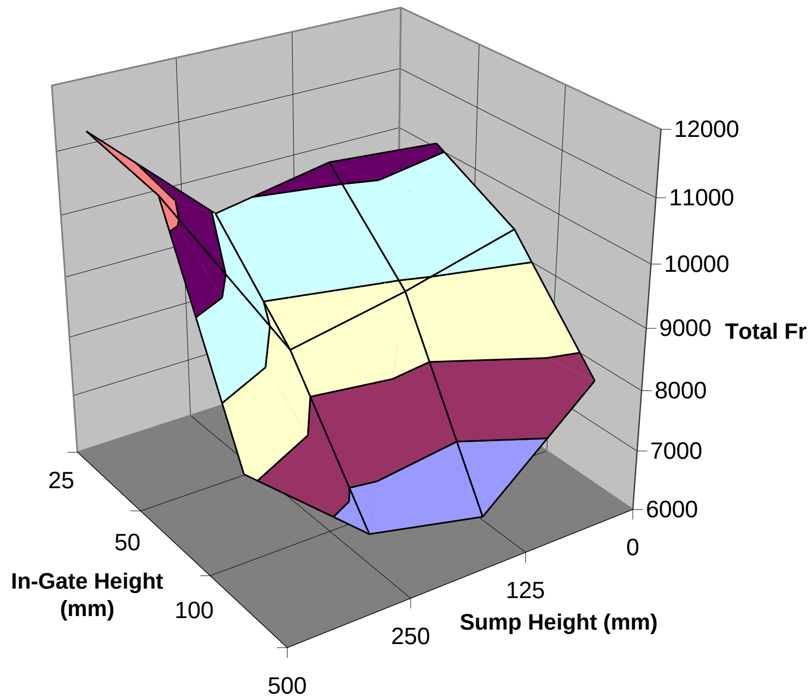


Figure 5. Response surface: Fr v. sump height v. in-gate height

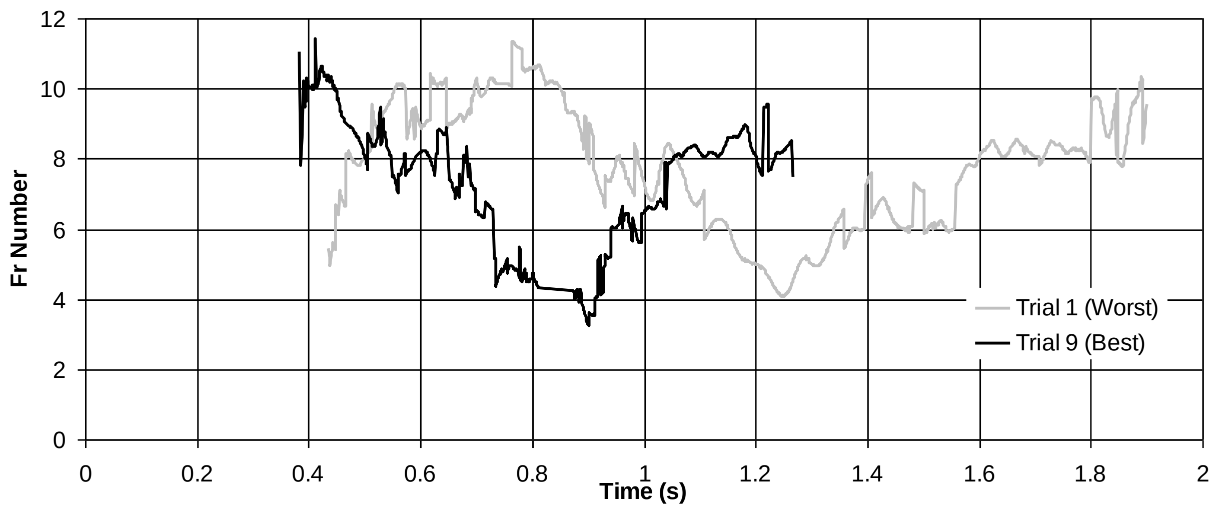


Figure 6. Fr Number Vs Time Plot for best and worst cases

Conclusions

1. The design of a casting's in-gate is of upmost importance, as this controls the rate of back pressurisation and thus the period required to prime the area between the in-gate and the down sprue.
2. The design of a sump is critical to its effectiveness as an incorrectly designed sump can be extremely detrimental to casting integrity.
3. Interaction is present between the sump and in-gate design and casting integrity, so therefore the system must be designed as a whole.

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